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Diamonds in Nature

A Guide to Rough Diamonds



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 Springer

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Preface

Diamond is undoubtedly one of the most well-recognized and sought-after materials. The use of diamond as a gemstone is deeply ingrained in many cultures, and a range of attributes are associated with diamond, such as it being the symbol of wealth and love. Despite their popularity as a gemstone, relatively little attention is paid to the mineral diamond in its naturally occurring form.

In this book we focus exclusively on natural, uncut diamonds and their characteristic features, such as their crystal morphologies, their colors, their surface textures, and the types of inclusion they contain. We elucidate how these features not only provide insights into the growth processes of diamonds, but also into the workings of our planet's interior.

A number of popular books have been written about diamonds, but few of these discuss the unique features of natural diamonds in any detail. More information can be found in the scientific literature, but this literature is scattered over many disciplines, including physics, geology, mineralogy, gemology, and material science. Due to the vast number of scientific articles that have been published about diamonds, it is difficult to provide a comprehensive overview of the literature. The references provided throughout this book, therefore, should only be regarded as a starting point from which the interested reader can delve deeper into the world of diamonds in nature.

Acknowledgments

Most of the diamonds shown in this book are museum or research specimens. Among those, a large proportion are on display in the Mineralogy and Petrology Museum at the University of Alberta in Edmonton, Canada. The diamonds for this exhibit were graciously donated by DeBeers through the Diamond Trading Company (DTC) and by Jeff Harris. Additional diamond specimens photographed for this book came from the mineral collection of the South Australian Museum in Adelaide, Australia. We thank Allan Pring for providing us with access to these diamonds. A detailed list of the diamond and rock specimens from these collections can be found at the back of this book. The diamonds from Boa Vista, Canastra, Arenapolis (Brazil), and from Jagersfontein (South Africa) were generously provided by Jeff Harris and DeBeers as research specimens. Additional diamonds came from Flinders Mines through Kevin Wills and John Foden; from Pascal Grundler; and from Thomas Stachel, who also gave us access to his research laboratory, microscope, and photography equipment.

We are also grateful to Petra Diamonds for providing us with the photographs of their exceptional diamonds, and to Ekati Diamond Mine and Argyle Diamond Mine who provided us with aerial photographs of their mining operations. Additional photographs came from Stephen Creighton and Graham Janson. Help and support with various aspects of imaging and photography were provided by Donald Chan, Anetta Banas, Heidi Höfer, Angus Netting, Peter Self, John Terlet, and Ryan McKellar. Comments on earlier versions of the manuscript by Shannon Zurevinski, Pascal Grundler, Jason French, Gerhard Brey, Karlis Muehlenbachs, Thomas Stachel, and Jeff Harris are gratefully acknowledged.

Chris Bendall handled the editorial aspects and encouraged us to pursue this project. For doing an excellent job in designing this book, we thank Susan Hunter.

An aerial photograph of a large-scale open-pit diamond mine. The central feature is a massive, circular, terraced excavation pit with steep, greyish-brown walls. To the right of the pit, there is a complex of industrial processing facilities, including several large white cylindrical storage tanks, various buildings, and a network of dirt roads. In the foreground, a large rectangular pond with a dark, possibly lined, bottom contains greenish water. Numerous yellow and white trucks are parked or moving around the site. The background shows a vast, flat landscape with scattered water bodies and a clear sky.

Chapter 1:
The Origin of Diamonds

Previous page –
Koala pit, Northwest
Territories, Canada.
Photo courtesy of BHP Billiton
EKATI Diamond Mine.

Chapter 1:

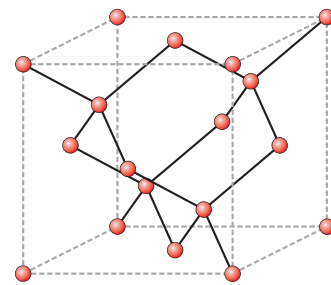
The Origin of Diamonds

Diamond, by definition, is a mineral composed exclusively of the element carbon. The carbon atoms in diamond are arranged in a dense cubic crystal structure (Fig. 1-01), and it is this crystal structure that gives diamond its unusual physical and chemical properties. Diamond is the hardest known naturally occurring mineral (Moh's hardness 10), but despite this extreme hardness, it is also a brittle material that can fracture in response to severe force. Another unusual property of diamond is its resistance to reactions with most chemical agents, which makes diamond virtually inert. Diamond, however, can be oxidized, but the oxidation of diamond is generally restricted to high temperatures. The hardness and chemical resistance of diamond and its potential to be oxidized at high temperatures strongly influence the presence of diamonds in nature.

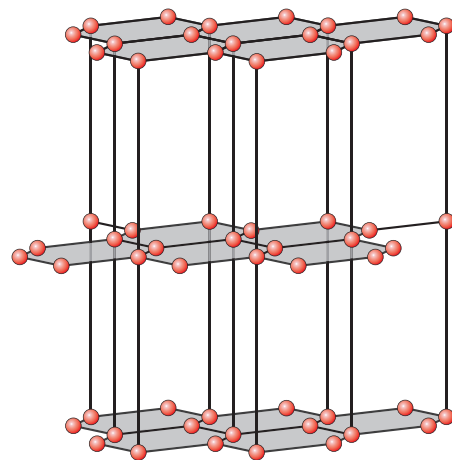
Diamond has a range of additional properties that make it an appealing and sought after mineral. Its high refractive index (2.4), for example, gives it an outstanding luster and makes it an attractive and extremely valuable gemstone. Diamond also has a high thermal conductivity, making it a valuable component in a wide range of technological applications.³¹⁴

In nature, carbon atoms only crystallize with the crystal structure of diamond at pressures exceeding several tens of thousands of bars.¹⁵³ At lower pressures, graphite is the stable form of carbon. Unlike diamond, graphite consists of layers of carbon atoms that are weakly bound to each other (Fig. 1-01). This crystal structure causes graphite to be one of the softest minerals in nature.

Even though diamond only forms at high pressures, it can survive in a low-pressure environment without converting to graphite. Pressures high enough to stabilize the crystal structure of diamond do not exist anywhere near the Earth's surface or even in the deeper parts of the Earth's crust. This means that the formation of diamonds in nature is always linked to very unique geological processes that involve high pressures.

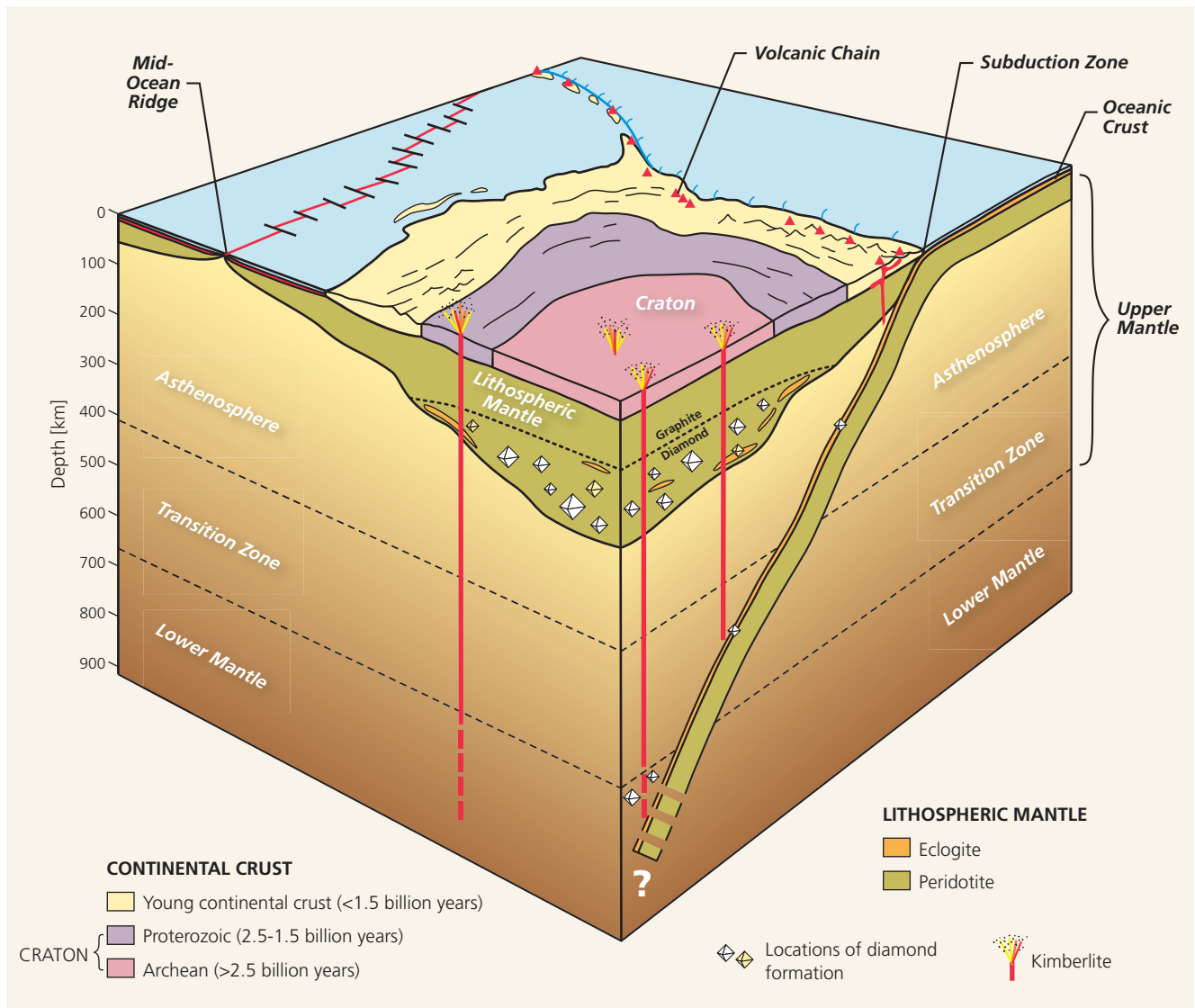


Diamond



Graphite

1-01: Crystal structures of diamond and graphite illustrating the different arrangements of carbon atoms in the crystal lattices of the two minerals. Drawn to scale.



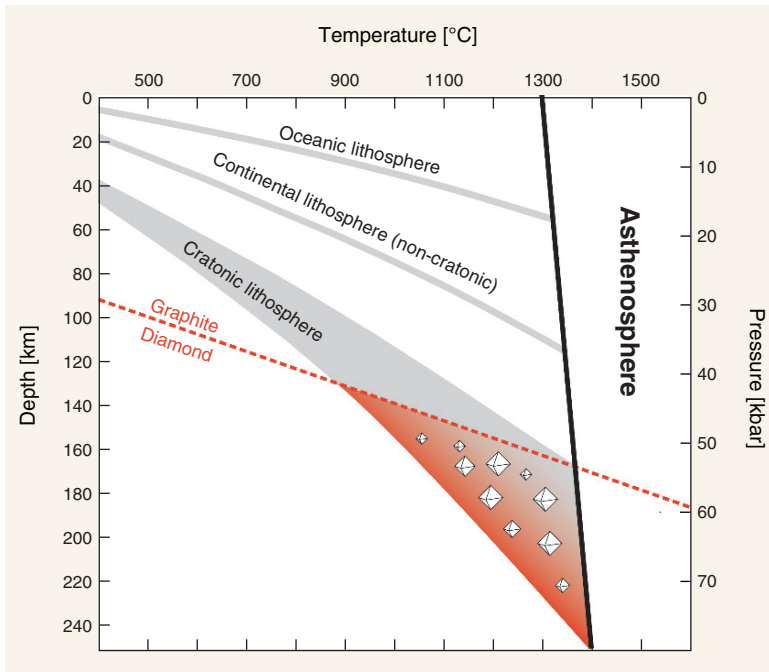
Artwork by Jason French and Raif Tappert.

1-02: Cross-section of the crust and mantle showing the main locations of diamond formation in the Earth's interior.

The origin of diamonds in the Earth's mantle

The vast majority of natural diamonds, including all gemstone diamonds, formed in the Earth's mantle at depths of more than 140 kilometers.^{10, 98, 193} Within the mantle, diamonds form primarily in the rigid part of the upper mantle, which is referred to as the lithospheric mantle (Fig. 1-02). The lithospheric mantle and the overlying crust constitute the tectonic plates that drift on the convecting asthenosphere. Unlike the lithospheric mantle, the typical asthenosphere does not appear to be favorable for diamond formation.²⁷²

In addition to high pressures, diamond formation is favored by relatively low temperatures. In nature, these conditions restrict diamond formation to regions with a very low geothermal gradient. Regions with such low geothermal gradients are generally confined to the geologically old parts of continents, which are referred to as cratons (Fig. 1-03).^{136, 242} Cratons are composed of crustal basement rocks, such as granites and gneisses that are more than ~1.5 billion years old. The lithospheric mantle roots beneath cratons can extend to depths of more than 250 kilometers, and due to their relatively low temperatures and extreme thicknesses, they



1-03: Pressure-temperature-depth diagram outlining the stability fields of diamond and graphite. Geothermal gradients for typical oceanic, continental, and cratonic lithospheres are shaded grey. Diamonds are only stable in cratonic settings at pressures greater than ~40 kilobars, which corresponds to depth of more than ~140 kilometers.

are the main locations of diamond formation in the Earth's mantle (Fig.1-02).²⁷⁵ Diamonds are believed to crystallize primarily from carbon-rich fluids that percolate through these lithospheric roots.^{158, 276}

Throughout Earth's history, magmas originating from deep within the mantle passed through the lithospheric roots. During their ascent, the magmas incorporated various minerals (xenocrysts) and rock fragments (xenoliths) from the surrounding mantle. The most common type of mantle rock is peridotite, which primarily consists of olivine and variable amounts of orthopyroxene, clinopyroxene, garnet, and/or spinel (chromite) (Fig. 1-04). A less common constituent of the mantle is eclogite,



1-04: A piece of the lithospheric mantle: peridotite xenolith from the Bultfontein mine, Kimberley, South Africa (Ø: ~30 cm), which consists mainly of olivine (dark green), garnet (purplish-red), Cr-diopside (bright green), and orthopyroxene (light brown).